Estimating the Geoelectric Field and Transmission Line Voltages During a Geomagnetic Storm in Alberta, Canada Using Empirical Magnetotelluric Impedance Data: The Influence of Three-dimensional Electrical Structures in the Lithosphere

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Abstract

Estimating the effect of geomagnetic disturbances on infrastructure is an important problem since they can induce damaging currents in electric power transmission lines. In this study, an array of magnetotelluric (MT) impedance measurements in Alberta and southeastern British Columbia are used to estimate the geoelectric field resulting from a magnetic storm on September 8, 2017. The resulting geoelectric field is compared to the geoelectric field calculated using the more common method involving a piecewise-continuous 1-D conductivity model. The 1-D model assumes horizontal layers, which result in orthogonal induced electric fields while the empirical MT impedance data account for fully 3-D electromagnetic induction. The geoelectric field derived from empirical MT impedance data demonstrates a preferential polarization in southern Alberta, and the geoelectric field magnitude is largest in northeastern Alberta where resistive Canadian Shield outcrops. The induced voltage in the Alberta transmission network is estimated to be ~120 V larger in northeastern Alberta when using the empirical MT impedances compared to the piecewise-continuous 1-D model. Transmission lines oriented northwest-southeast in southern Alberta have voltages which are 10-20% larger when using the MT impedances due to the polarized geoelectric field. As shown with forward modelling tests, the polarization is due to the Southern Alberta British Columbia conductor in the lower crust (20-30 km depth) that is associated with a Proterozoic tectonic suture zone. This forms an important link between ancient tectonic processes and modern-day geoelectric hazards that cannot be modelled with a 1-D analysis.

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October 12 Aurora, Edmonton, AB, Canada

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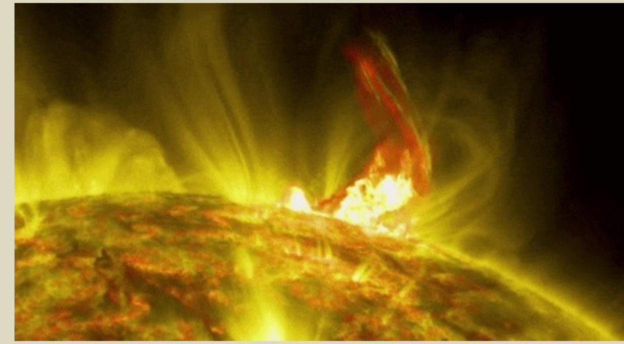
December 15, 2021

NSERC CRSNG

Background Information: Space Weather Hazards

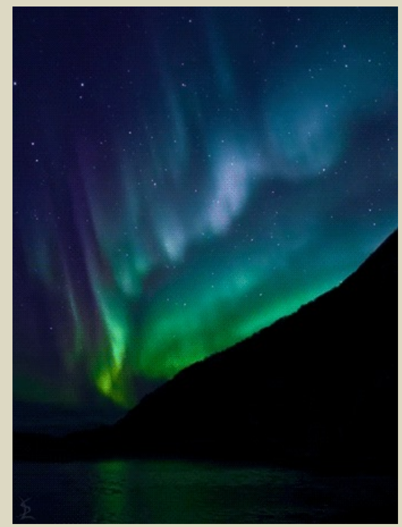
CME

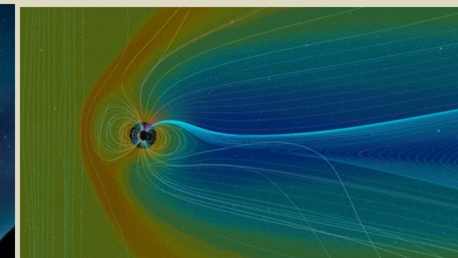
Coronal Mass Ejections
Where: Sun
Who: Heliophysics



GMD

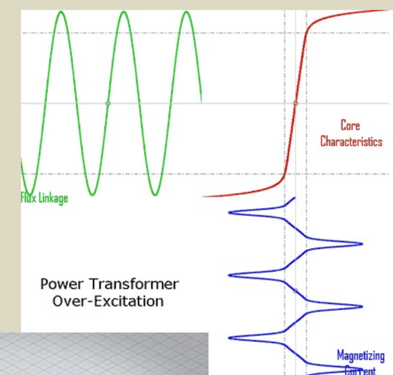
Geomagnetic Disturbance
Where: Sky
Who: Space Physics





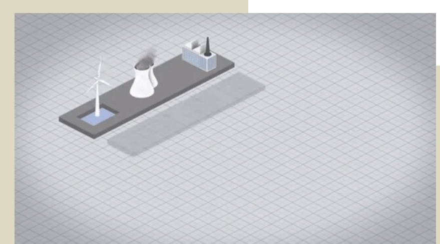
Geoele c Fields

The Induction
Where: Earth
Who: Geophysics



GIC

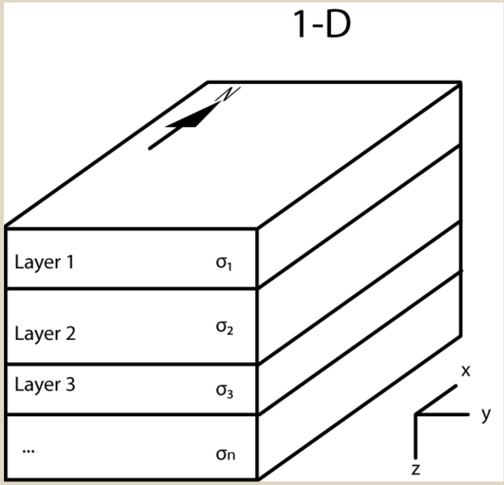
Geomagnetically-Induced Currents
Where: Power Transmission Networks
Who: Electrical Engineering



"1-D Model-Space Method"[1]

Common assumption: Locally 1-D Earth

$$\begin{bmatrix} E_x(\omega) \\ E_y(\omega) \end{bmatrix} = \begin{bmatrix} 0 & Z(\omega) \\ -Z(\omega) & 0 \end{bmatrix} \begin{bmatrix} H_x(\omega) \\ H_y(\omega) \end{bmatrix}$$

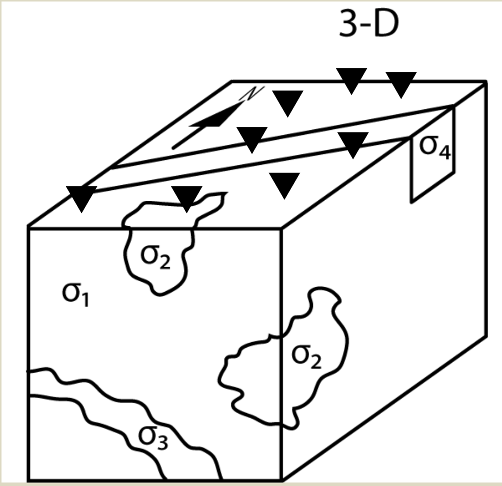


Impedance is calculated using *a priori* 1-D conductivity model

"Data-Space Method"[1]

Ability to Capture 3-D Earth Structure

$$\begin{bmatrix} E_x(\omega) \\ E_y(\omega) \end{bmatrix} = \begin{bmatrix} Z_{xx}(\omega) & Z_{xy}(\omega) \\ Z_{yx}(\omega) & Z_{yy}(\omega) \end{bmatrix} \begin{bmatrix} H_x(\omega) \\ H_y(\omega) \end{bmatrix}$$

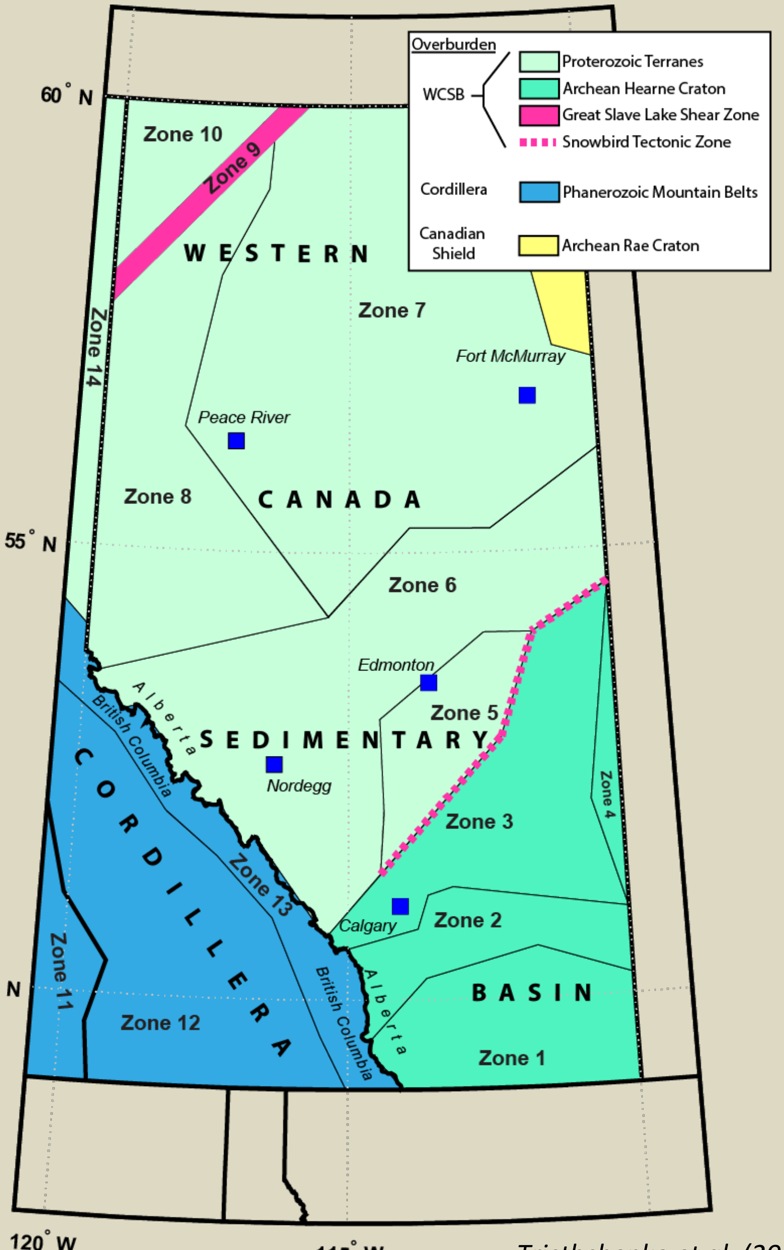


Impedance is measured using magnetotelluric instruments in the field

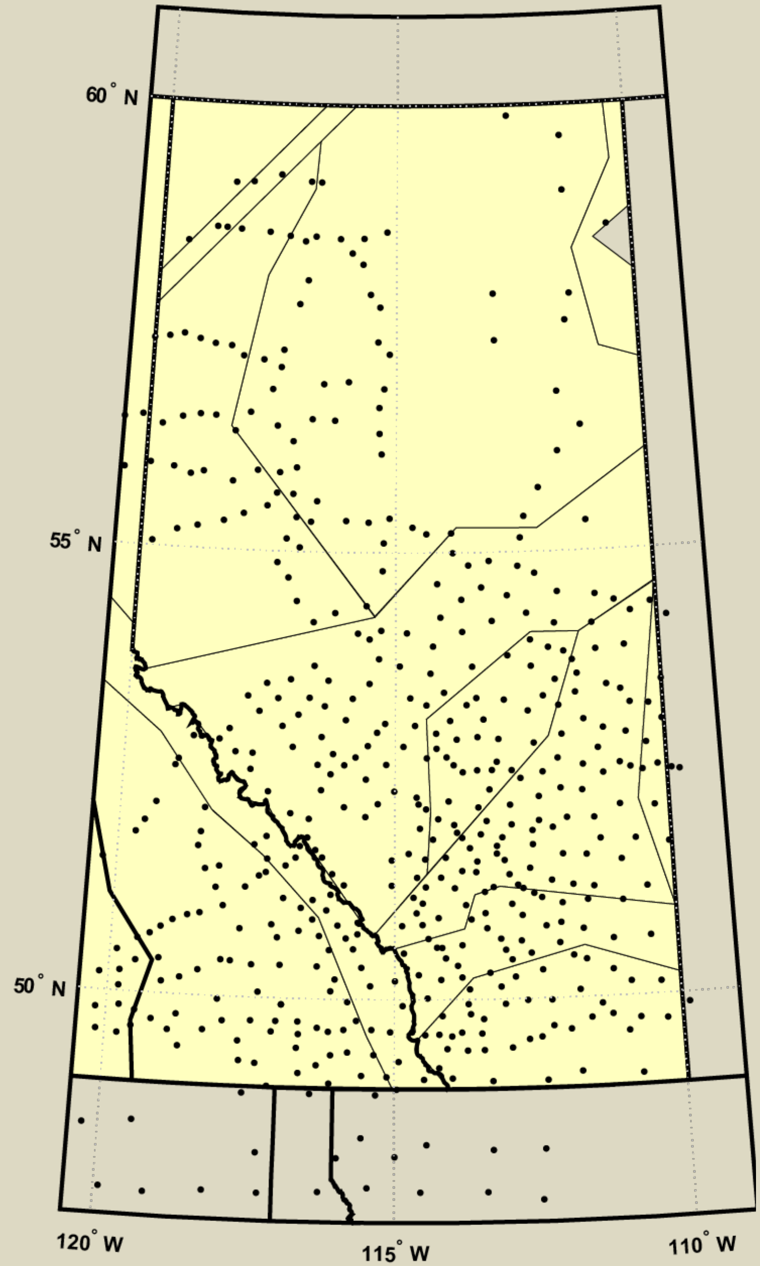
Question: Are there significant differences depending on the method you use?

[1]*Kelbert (2020)*

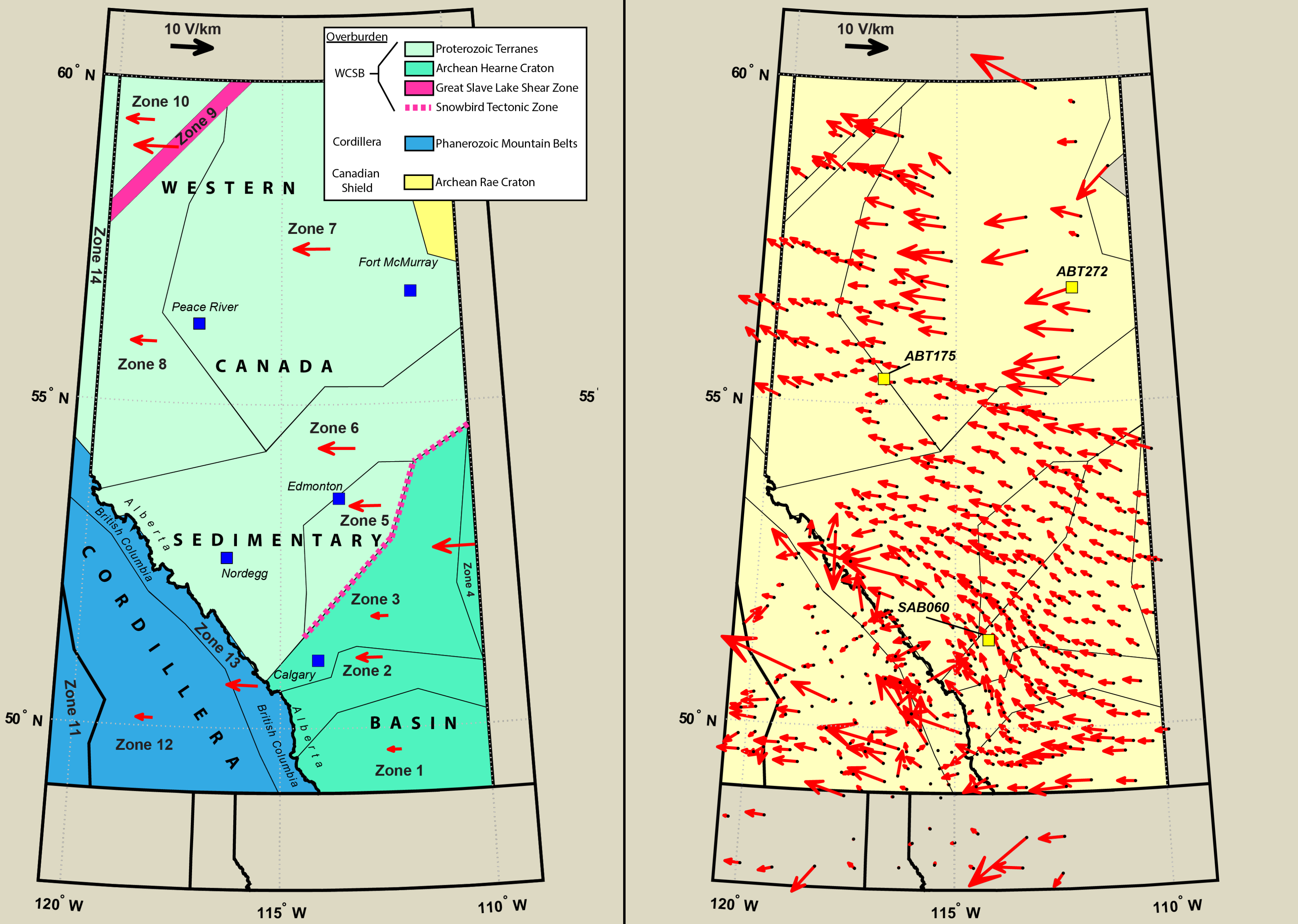
Background Information: Alberta Geology



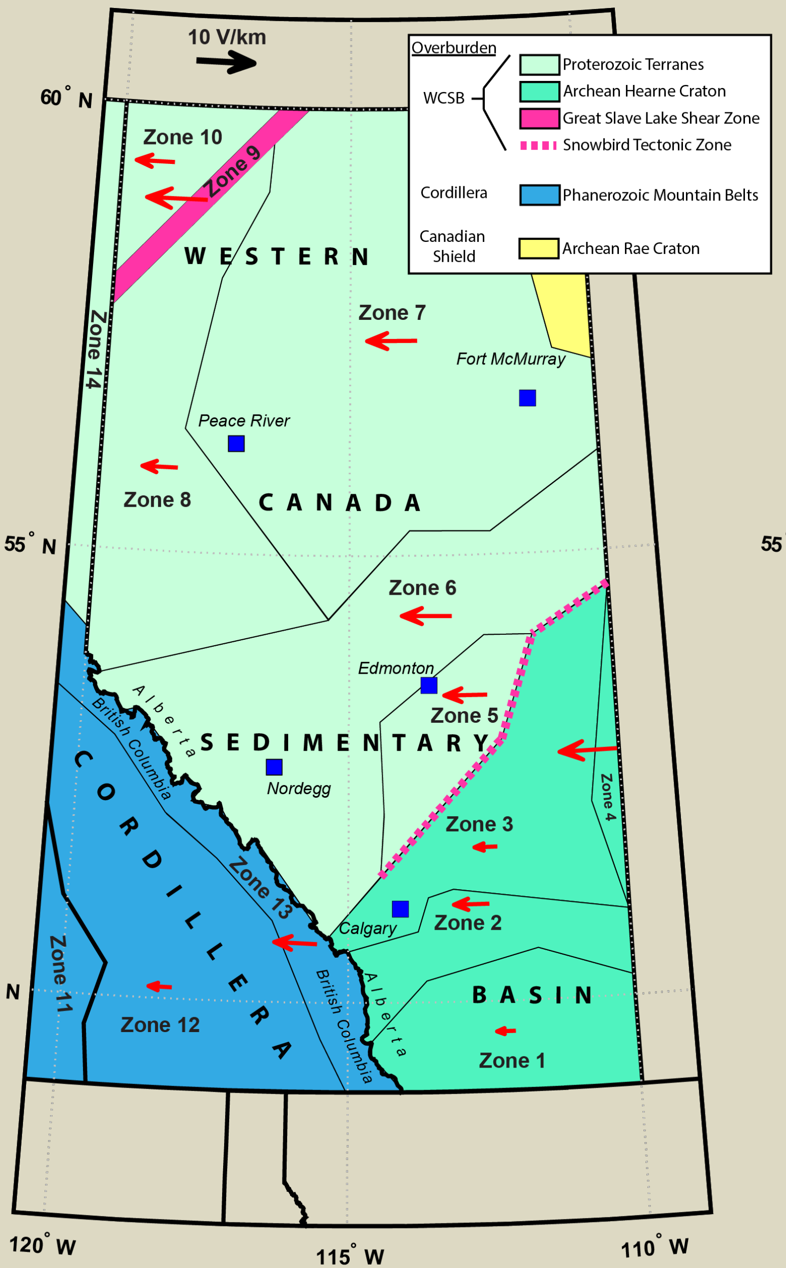
Tricthchenko et al. (2019)

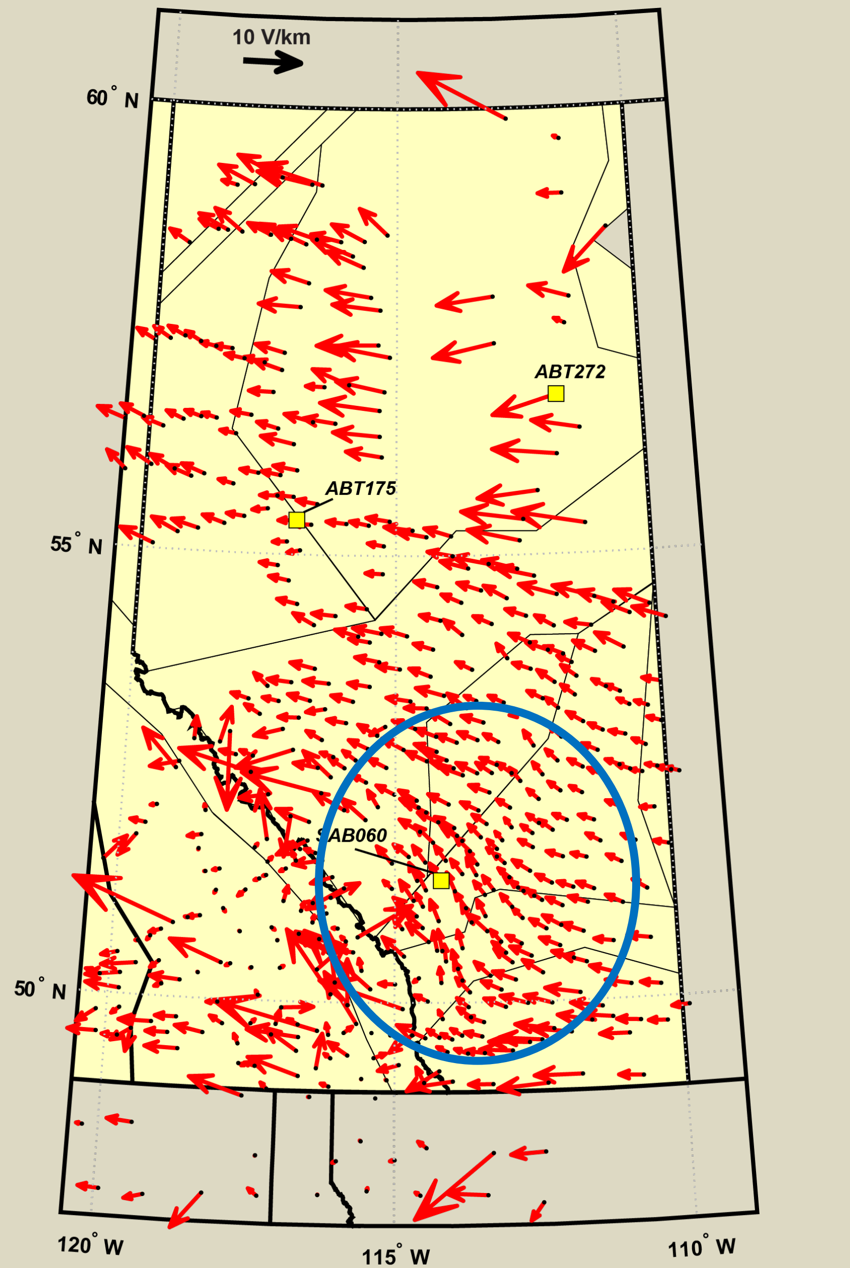


Test #1: Synthetic 1000 nT, north-polarized GMD at 0.01 Hz

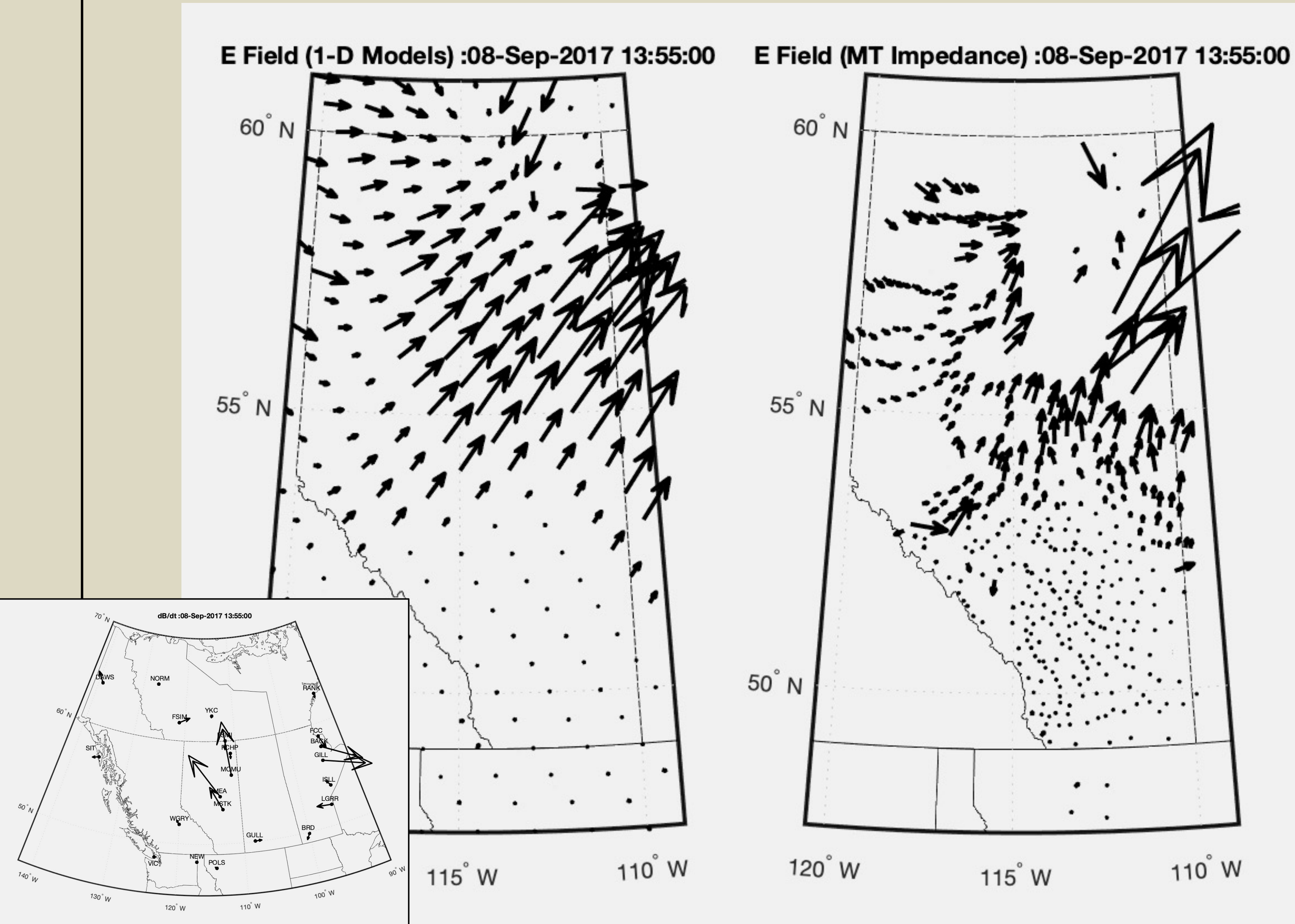


Test #1: Synthetic 1000 nT, north-polarized GMD at 0.01 Hz

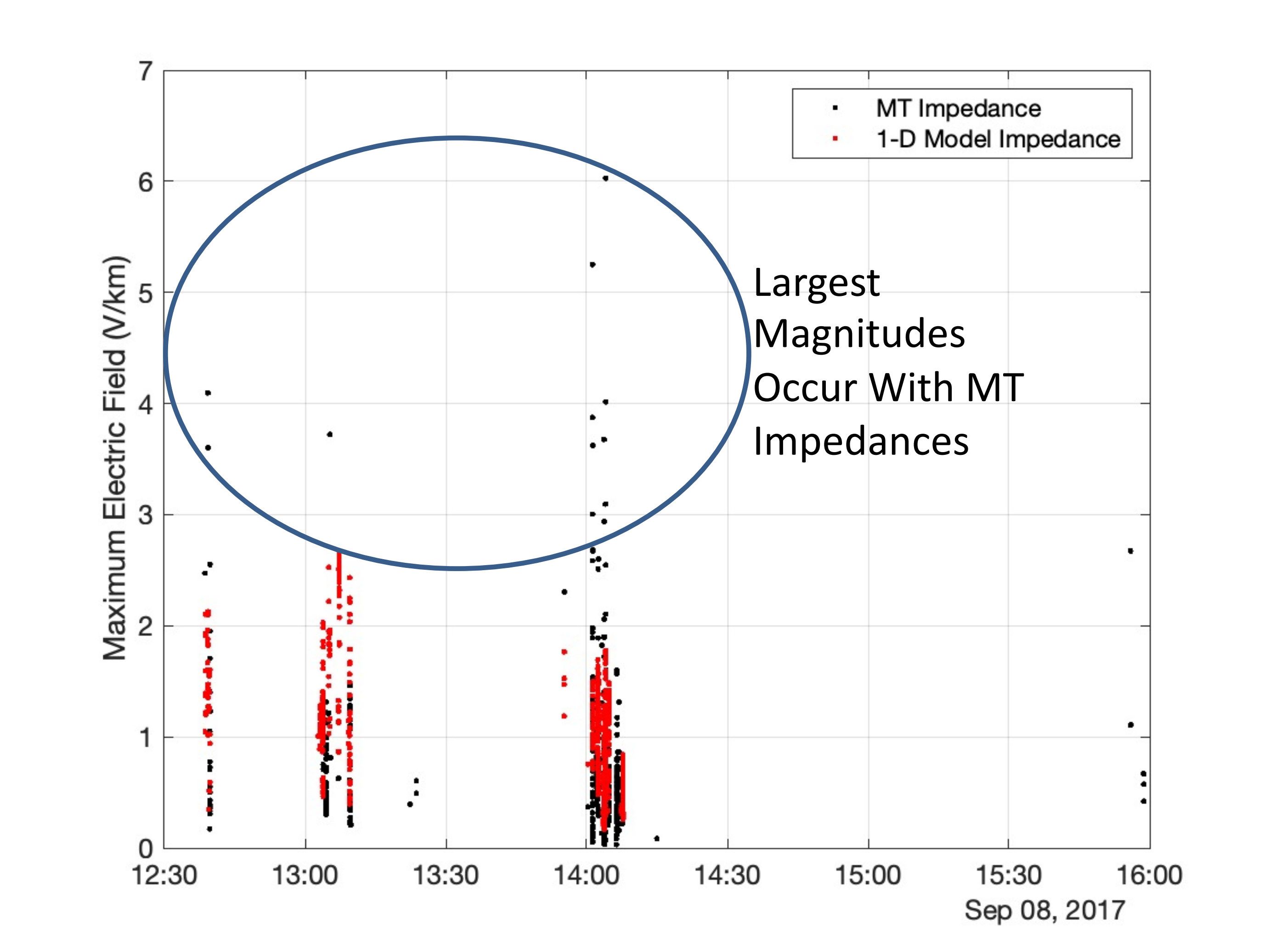




Test #2: Real Storm from September 8, 2017 in Time-Domain

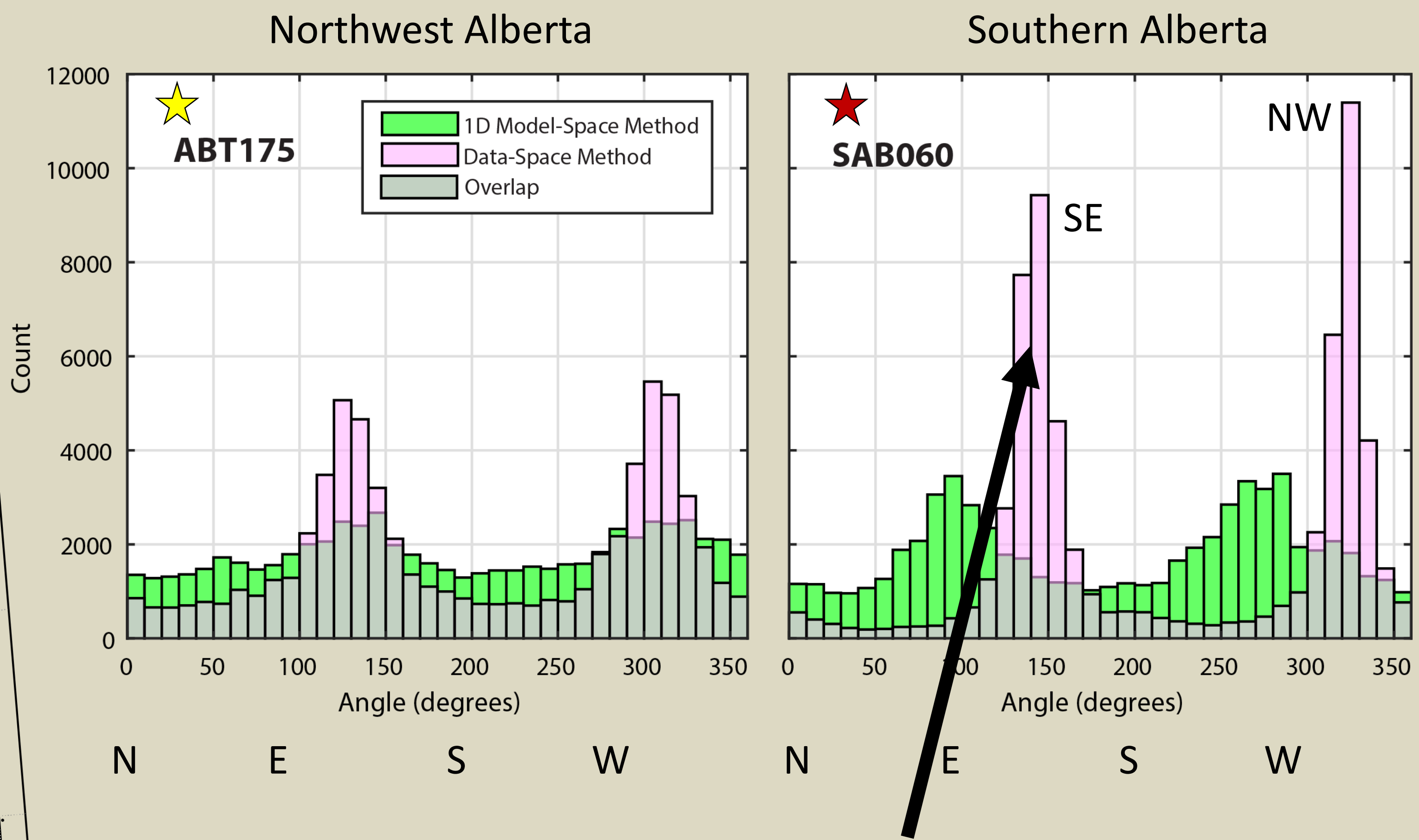


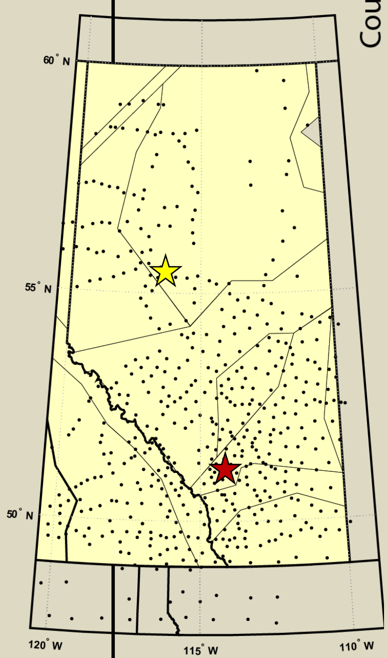
Test #2: Peak Geoelectric Field Magnitude



Test #2: Direction

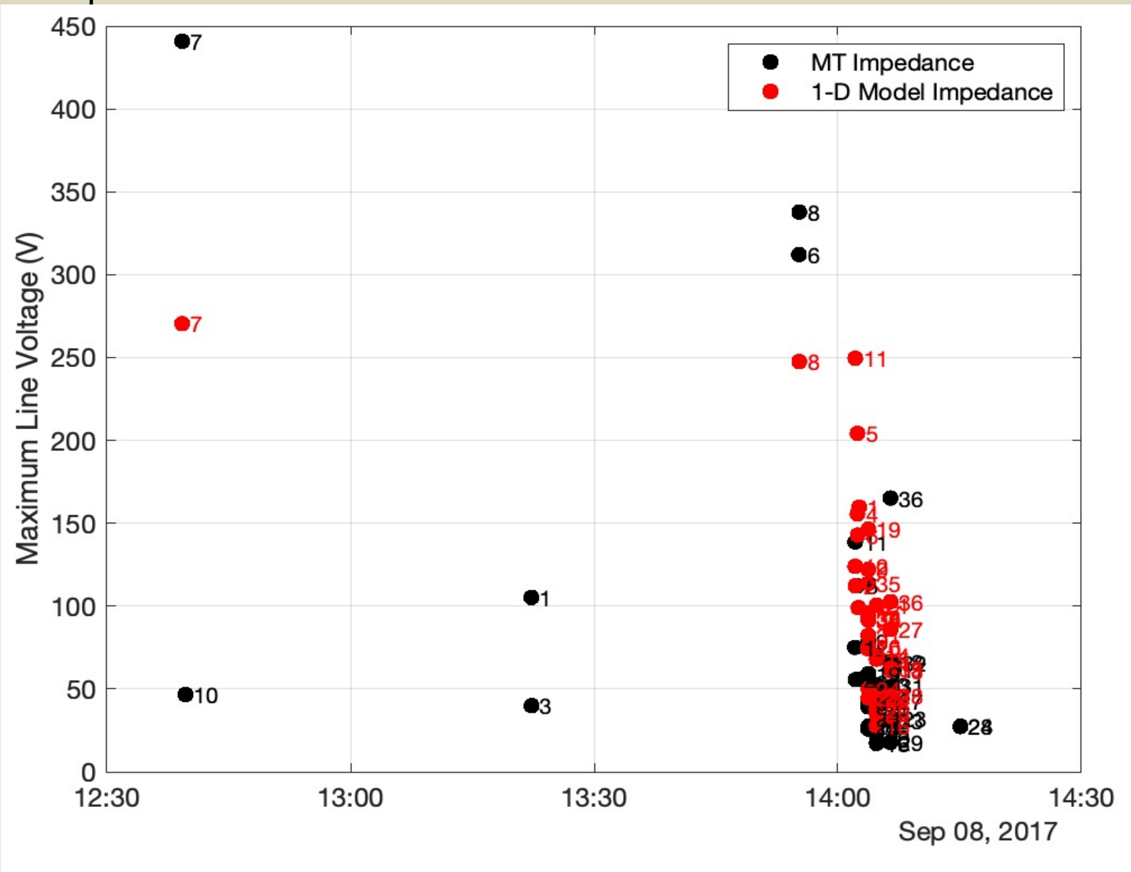
- Direction of the E-field computed at all times (06:00:00 to 23:59:59) for 2 locations

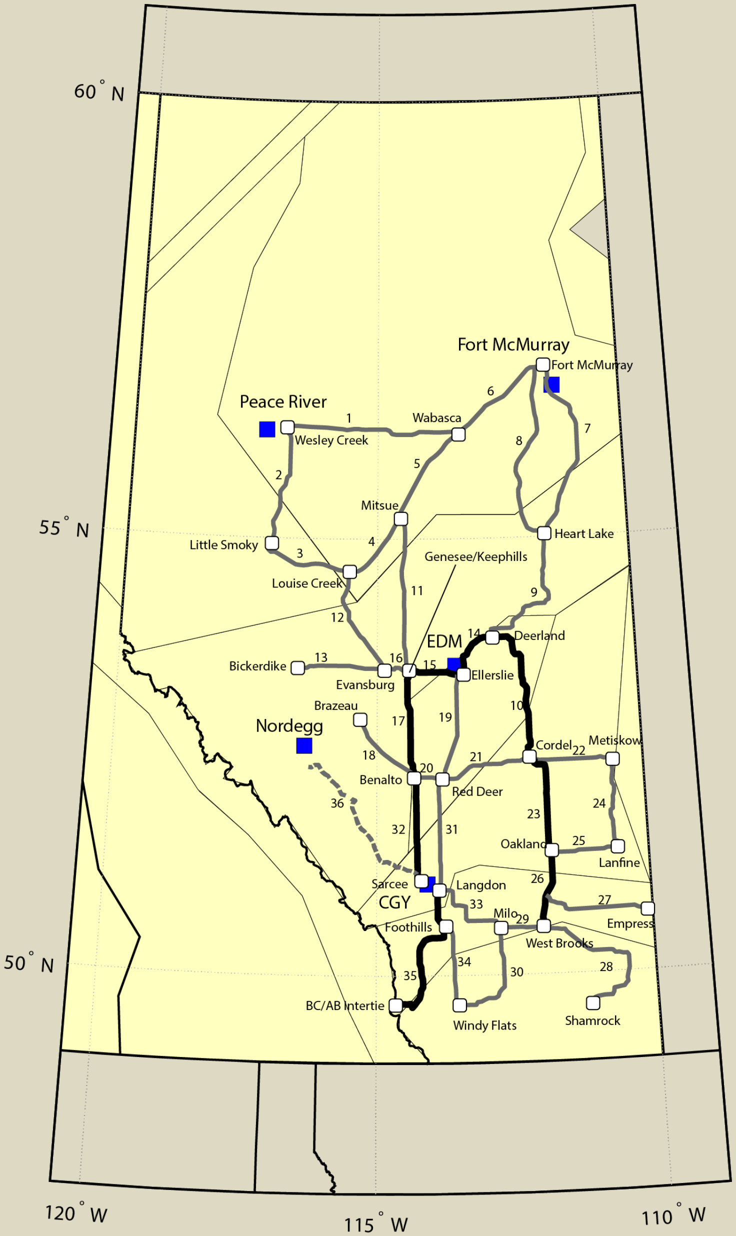




Partially-polarized geoelectric field is most apparent in southern Alberta

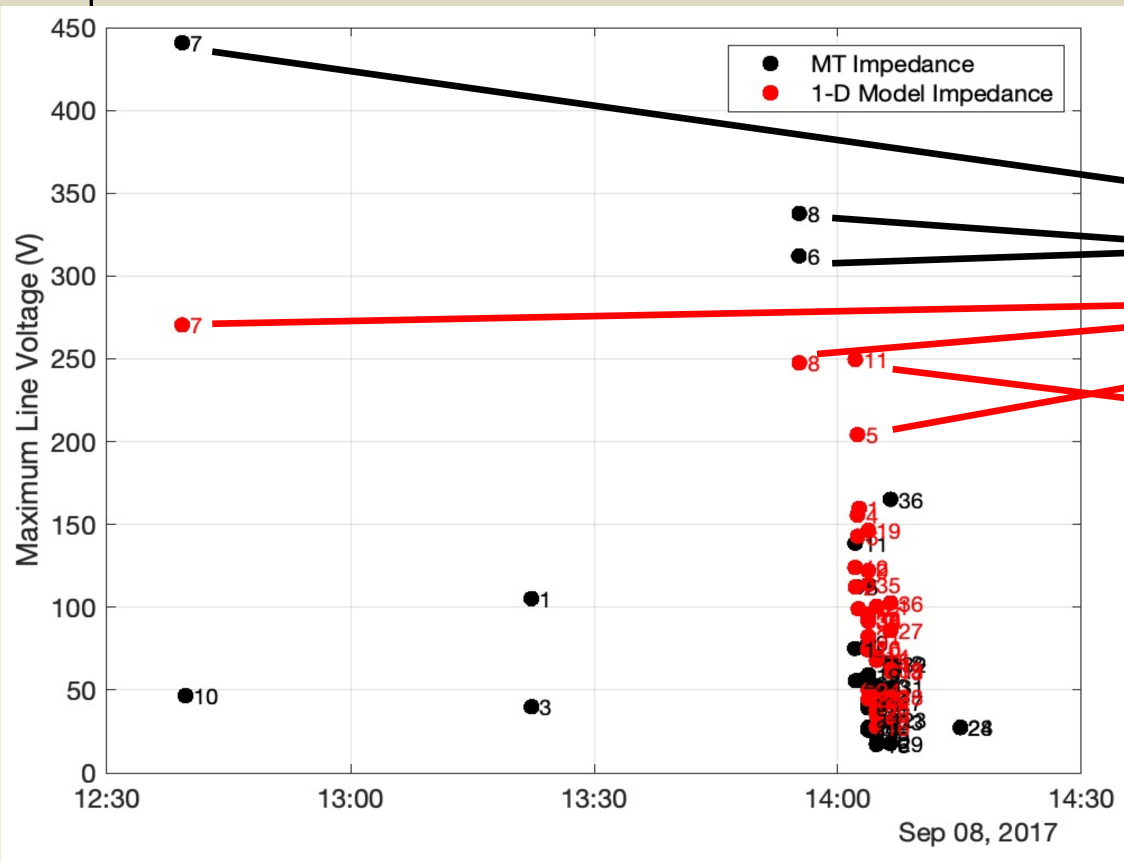
Test #3: Line Voltages

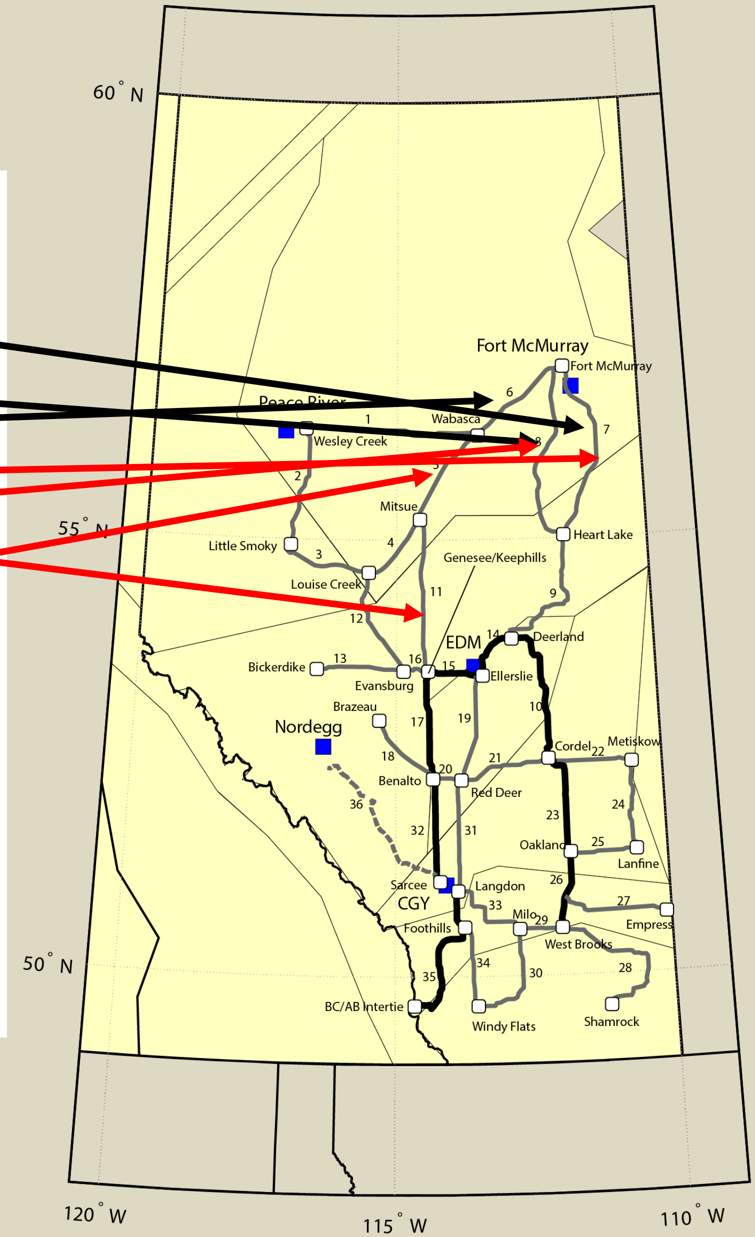




Test #3: Line Voltages

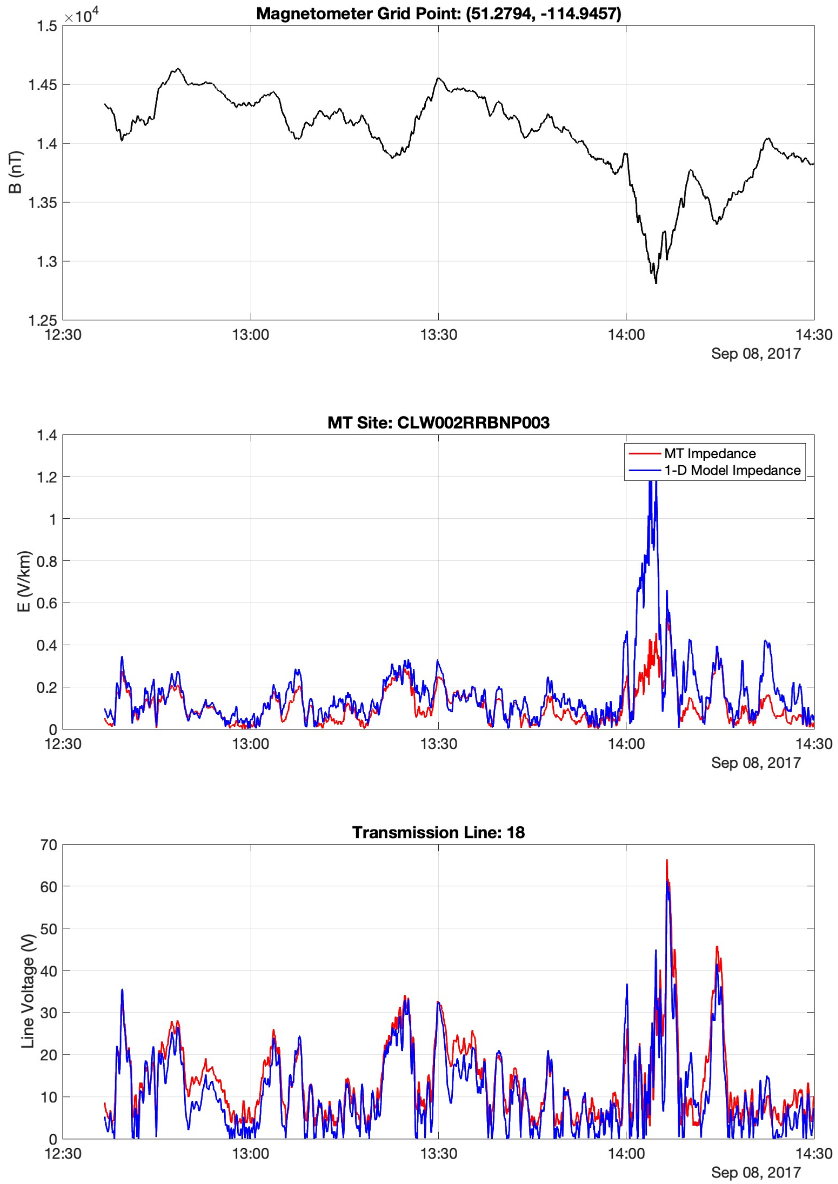
- MT impedance results in larger peak voltages in northern Alberta

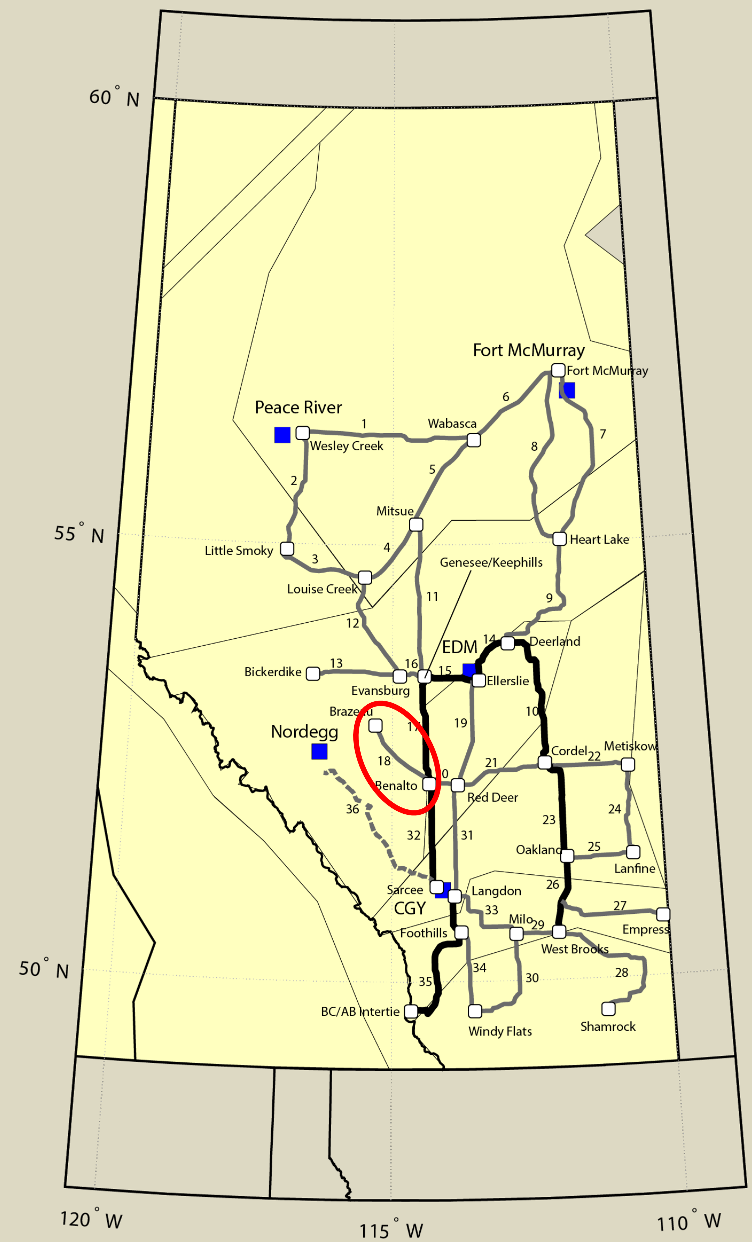




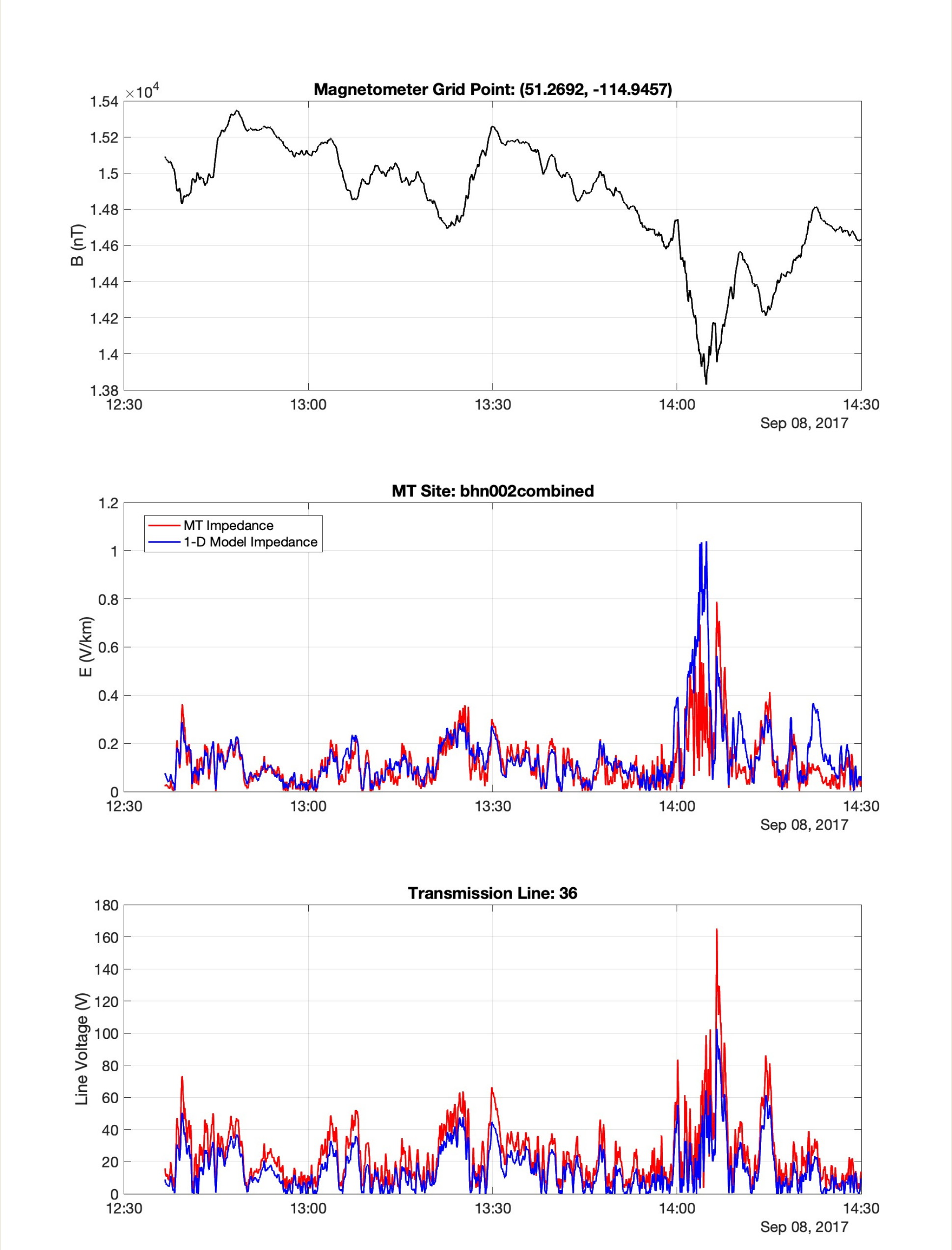
Test #3: Line Voltages

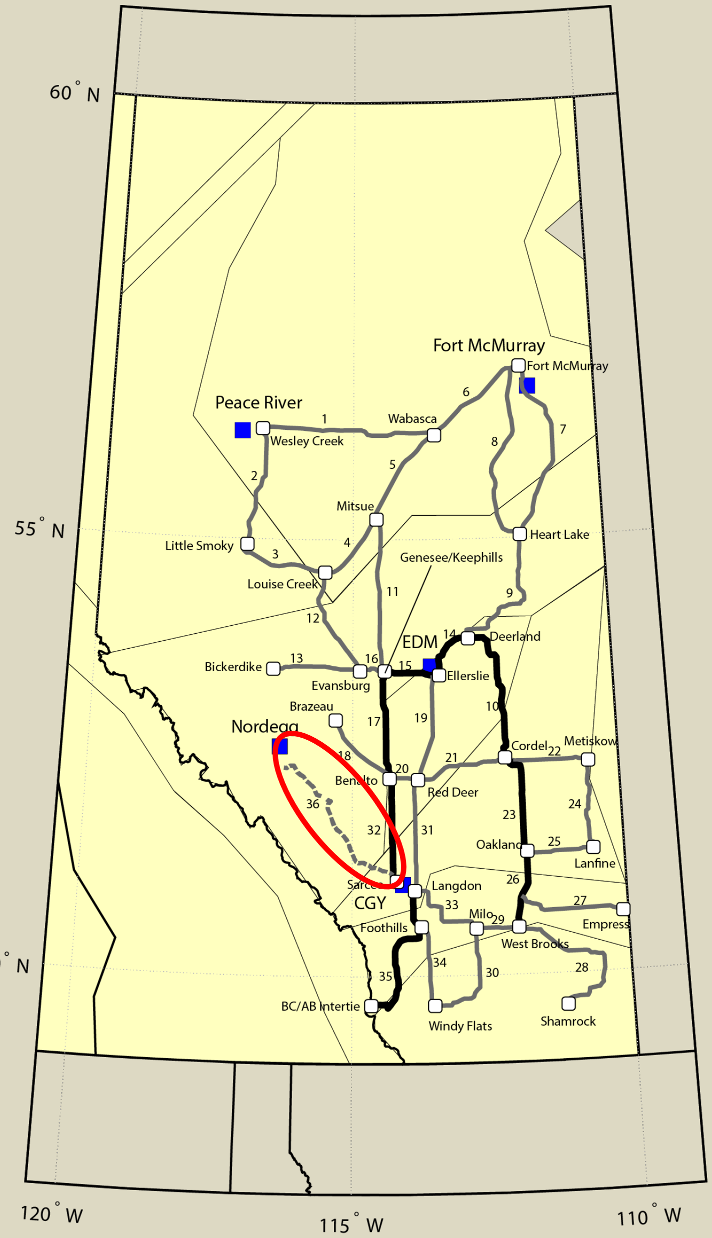
What about the polarization?



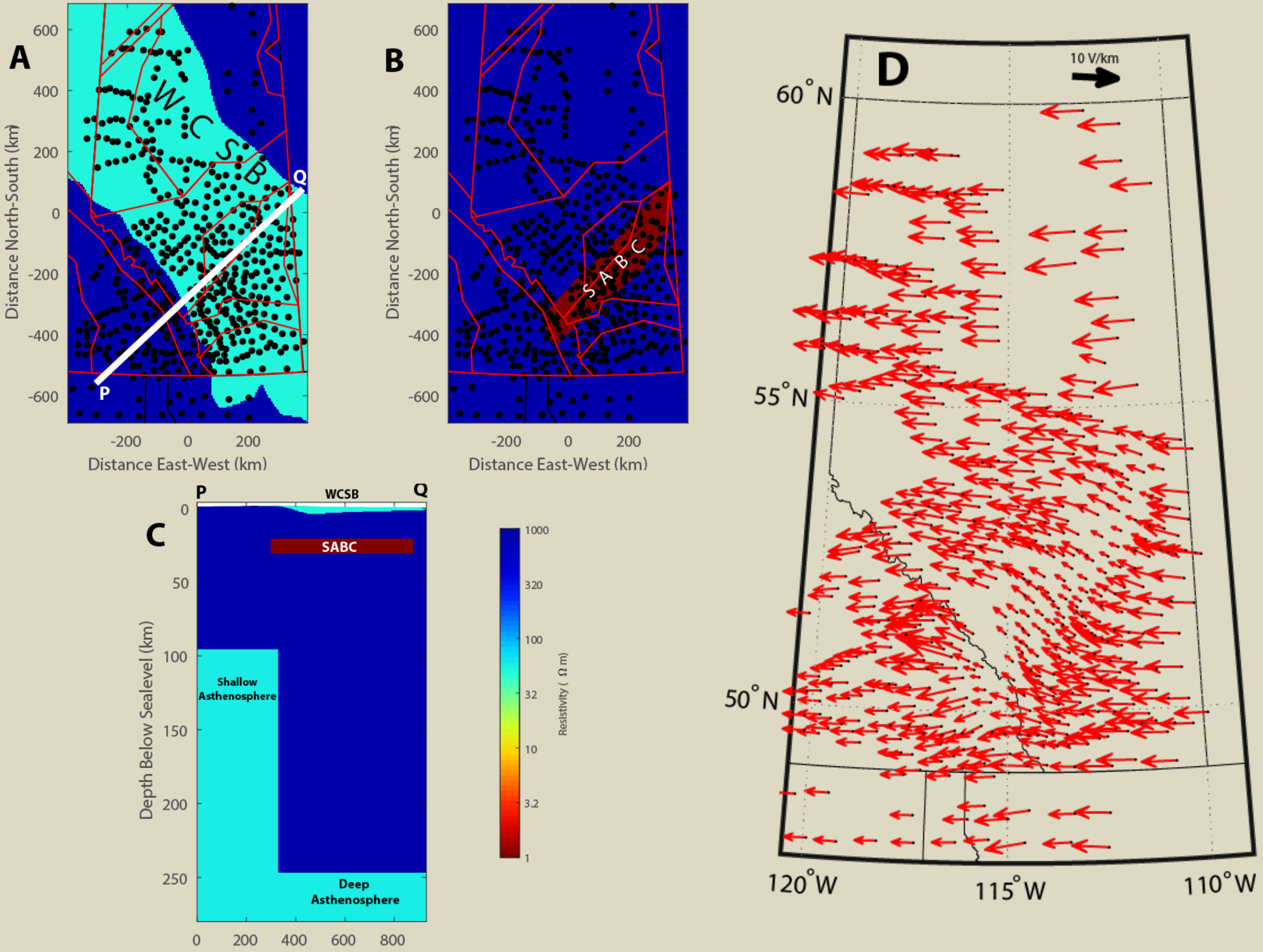


Test #3: Line Voltages





Geological Explanation



Conclusions and Future Directions

- NE Alberta has largest discrepancies and largest magnitudes
- Transmission line voltages can be >100 V larger depending on method
- Partial polarization of the geoelectric field in southern Alberta has subtle effect
- Different geology, different GMD, or different transmission networks could magnify this effect
- Ancient tectonics on stable continents can play a role in influencing space weather hazards today